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ABSTRACT

The formation of an organic deposit on the spiral concentrators of the Quebec Cartier Mining Company Mount Wright Plant, Fermont, Quebec, altered the geometry of the spirals, thereby decreasing the efficiency of the operation of the concentrators. The organic deposit and the process water at the plant were found to be contaminated with bacteria capable of slime formation. Analysis of samples obtained from various locations within the plant and from process water sources indicated that the source of contamination and the metabolites for the organisms arise from the percolation of sewage into Hesse Lake. Prevention of contamination of Hesse Lake with sewage, sterilization of the plant and chlorination of the process water until the metabolite levels in Hesse Lake drop to normal levels (less than 15 micrograms per litre) are recommended.

LE RÔLE DES BACTÉRIES DANS LA FORMATION LES DÉPÔTS ORGANIQUES SUR LES SURFACES DES CONCENTRATEURS EN SPIRALES DE L'USINE MOUNT WRIGHT DE LA COMPAGNIE MINIÈRE QUÉBEC CARTIER

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RÉSUMÉ

La formation d'un dépôt organique sur les surfaces des concentrateurs en spirale de l'usine Mount Wright de la Compagnie Minière Québec Cartier (QCM), Fermont, Québec, a modifié la géométrie de ces surfaces et, par conséquence, a diminué l'efficacité de l'opération de ces concentrateurs. Des espèces de bactéries qui synthétisent des matériaux vaseux ont été trouvées dans le dépôt organique et dans l'eau du procédé. L'analyse des échantillons de l'eau du procédé provenant de différents lieux a démontré que la source de contamination et des métabolites essentiels pour les microorganismes provenait du dévesement l'induction des eaux-vannes dans le lac Hesse. On propose que la contamination du lac Hesse par les eaux-vannes cesse, que l'usine soit stérélisée, et que l'eau du procédé soit traitée avec du chlore jusqu'à ce que les concentrations des glucides reviennent à des niveaux normaux (moins que 15 micrograms par mL).

INTRODUCTION

The Quebec Cartier Mining Company, Mount Wright Plant (QCM), Fermont, Quebec, processes 130,000 to 150,000 tonnes per day of a fine grained 30% iron specular hematite ore. The ore is crushed and ground to less than (1.40 mm) 14 mesh, and pumped at 35% solids to a spiral concentrator unit (used for separating the crushed ore into concentrate, middlings and tailings) consisting of 8640 single spirals. Approximately 86% of the iron is recovered in the concentrate which contains approximately 66% iron in about 40% of the original mass of the ore. The tailings contain about 8% iron in approximately 60% of the original mass of the ore, and are discarded as waste. The middlings are returned to the grinding circuit and are reprocessed (1).

A problem that has arisen in the spiral concentrators decreases the efficiency of this operation. An organic deposit (crud) forms in the spirals, altering their geometry. This results in poor separation of the concentrate from the tailings and an increase in the proportion of the iron reporting to the middlings. As the middlings must be reground, the energy requirements of the grinding circuit are increased, thereby increasing processing costs. Furthermore, overgrinding can result in losses of fine iron minerals to tailings.

Spiral deposits have been a problem within the QCM circuit since 1977. Commercial laboratories have previously analyzed the organic deposits and have identified enteric coliform bacteria in a few of the samples. The problem of the

organic deposit formation was brought to the attention of a CANMET offical during a visit to the plant. One of the authors visited QCM and collected process water samples from various locations within the mill circuit. Analysis of these samples identified the source of contamination and the metabolites supporting the growth of the organisms.

In natural and industrial aquatic environments high concentrations of bacteria, surrounded by an extra-cellular polysaccharide component called the glycocalyx, are frequently found on surfaces. These glycocalyx-enclosed microcolonies form stable films which tend to enlarge and may contain one or a number of different species of bacteria. The bacterial population is attached on submerged surfaces, and withdraws nutrients very efficiently from the water flowing over the film. The glycocalyx also protects the bacterial cells from physical and chemical agents (3).

Figure 1 shows the diagrammatic representation of a bacterial cell. Capsules, slime and the cell wall and their relationship is shown clearly in the diagram. The slimes and capsules are composed of polysaccharides, lipopolysaccharides and other sugars. Because of their composition they act as strong adhesives under certain industrial situations as seen in the spiral deposit.

Samples of the organic deposits and water were obtained from various locations in the mill and the bacteria were

identified and the cellular concentration was determined to locate the source of contamination. These samples were also analyzed to determine the carbon and energy sources present which sustained the bacterial growth.

MATERIALS AND METHODS

Samples of organic deposit found on the surface of the spiral concentrators were obtained from QCM. Liquid samples were collected in sterile plastic bottles from eighteen locations at the plant. The sampling locations are listed in Table 1 and are indicated in Figures 2 and 3.

A suspension of the organic deposit was prepared using sterile water. A standard loopful of this suspension, streaked on to nutrient agar plates, was incubated for 72 hours. The individual colonies which developed on the plates were then subcultured. Gram-negative rod-shaped bacteria capable of growth on carbohydrates were identified using the Enterotube II and Oxi/Ferm diagnostic systems (Hoffman La Roche Limited, Mississauga, Ontario). Non-enteric bacteria (Corynebacterium, Arthrobacter, Norcardia, and Streptomyces) were identified from their morphology, acid-fast staining characteristics, and growth on sugars other than those contained in the above diagnostic systems. Slime generation was observed by growing the bacteria isolated from the organic deposit in a defined liquid medium (4) containing 0.1% glucose or sucrose (Table 2).

The bacteria were enumerated by the pour plate method (5), in which 1.0 mL aliquots of the liquid samples, or five

ten-fold serial dilutions thereof, were placed in sterile petri dishes with about 10 mL of melted agar medium (45oC). Levines EMB agar was used for the enumeration of enteric and faecal coliform bacteria, and nutrient agar was used for the enumeration of total bacteria. After 72 hours, the colony-forming units in each plate were counted with the aid of a Quebec Colony Counter. The average number of colonies was multiplied by the reciprocal of the dilution to give the bacterial concentrations per mL of original sample.

Carbohydrate concentrations were determined colorimetrically with anthrone (6), total organic carbon was determined by combustion, and total dissolved solids were determined gravimetrically.

RESULTS

The identification of microorganisms, isolated from the organic deposit and the water samples obtained from the plant, are shown in Table 3. Both enteric bacteria originating from the intestinal tract of warm-blooded animals and microorganisms commonly found in soil, dust and surface water were detected. Of the enteric bacteria, only the faecal coliform Klebsiella oxytoca produced copious amounts of capsular material. The soil bacteria were identified as Pseudomonas fluorescens, a Norcardia species, and two isolates of the genus Corynebacterium which also produced large amounts of capsular material, whereas all other microorganisms identified produced only minor quantities of

capsular material.

Table 4 shows the concentrations of faecal coliforms, enteric bacteria and total bacteria from the water samples of the mill. The concentrations of carbohydrate carbon, total organic carbon and total dissolved solids present in the liquid samples are presented in Table 5. The carbohydrate carbon is expressed as mg carbon per litre.

Bacteria in all samples were able to grow and produce capsular material when incubated in the presence of air at 20oC in a medium containing mineral salts and a sugar. Calgon M 502, the additive used by QCM for thickening, when used as the sole carbon-source did not support growth of these bacteria at concentrations between 0.001 and 10% (v/v).

DISCUSSIONS

Microorganisms which cause slime deposit formation are either of soil origin and belong to the Pseudomonas and Flavobacterium, or originate in the intestines of warm-blooded animals and belong to the genus Klebsiella (formerly known as Aerobacter) (2). All three genera are present in both the organic deposit from the spiral concentrators and in the process water. In addition, enteric bacteria originating from sewage were detected.

The presence of enteric bacteria , including faecal coliforms, in the organic deposit from the spiral concentrators

suggests sewage contamination of the mill process water as the probable cause for the formation of this deposit. The detection of large concentrations of these bacteria in the process water further reinforces this thesis.

The sources of make-up water determine the type and number of microorganisms introduced into the mill system(2). Surface water, free from sewage, generally contains small concentrations (usually less than 100 cells/mL) of microorganisms, mainly of soil origin. Water polluted by pasture run-off or sewage will contain bacteria of intestinal origin (enteric bacteria) which may be present in large concentrations (>1,000 cells/mL). When polluted water is used for industrial purposes, the bacteria enter the plant circuit, and grow and multiply by using the organic compounds present as their energy source.

Bacteria proliferate in plant locations such as holding tanks, sumps, or attached to the interior walls of pipes and exposed to a flowing stream of nutrient containing water (3). Biofouling of pipes is a very serious problem to many industries (7). When attached to a surface , bacteria can efficiently remove nutrients from solution, and multiply with the formation of a very concentrated cell mass (2). The process water of the Mount Wright mill contains 5 to 25 mg/L of total organic carbon. The carbohydrate carbon, which is available to organisms as a nutrient, varies from 0.6 to 5 mg/L. Carbohydrate content, measured as glucose, varies from 1.5 to 12.1 mg/L.

High concentrations of enteric bacteria and the presence of faecal coliforms at locations 1, 2 & 5 indicates that the Hesse Lake is contaminated with sewage. The origin of this pollution appears to be the sewage overflow from the settling ponds and filtration lagoons (locations 6 to 8) which percolates into Hesse Lake. The water sample obtained from the in-take sump in the pumphouse near Hesse Lake (sample 5) has a total organic carbon content of 5.9 mg/L of which 2.2 mg/L is in a form which can be readily utilized by the microorganisms as nutrient.

Table 4 shows that the samples obtained from Hesse Lake and the sump (in-take for the pumps), sample numbers 1, 2 & 5, have faecal coliform and enteric bacteria and the carbohydrate carbon, which is the nutrient for the bacteria, is more than 2 mg per litre. The maximum concentrations of sugars in Canadian lakes have been reported to be 10 micrograms of sucrose and 5 micrograms of glucose (8). Sample number 8, obtained from the filtration lagoon, which receives the overflow from the sewage sedimentation tank, had 4.8 mg/L of carbohydrate carbon and the concentrations of faecal coliform bacteria and enteric bacteria were 1,017/mL and 5,380/mL respectively. Sample numbers 13 to 16, from the surface of thickener # 1, and the head tanks of the rougher, cleaner and recleaner spirals, respectively, had over 4 mg/L of cabohydrate carbon. For practical purposes, the amount of nutrient available for the bacteria is at the same concentration as that found in the overflow from the sewage settling pond. The maximum concentration of enteric bacteria

were detected in samples 6 and 18, which were obtained from the settling pond and the mill discharge respectively. The concentration of total organic carbon was highest in the mill discharge, probably due to the introduction of soil organic matter from the open pit. Although, the organic carbon is high, the carbohydrate carbon was only about 1 mg/L, which may be due to its depletion by the organisms present. The grinding mill, being inside the plant building, is maintained at a temperature that will support active bacterial growth. Moreover, the water in the mill receives maximum aeration and the bacterial cells growing in this part of the circuit are not exposed to the same abrasion by fine particles that may occur later in the circuit. The high concentration of enteric bacteria in the mill discharge could be due to the fact that it is the most suitable location for the attachment and growth of enteric type organisms.

RECOMMENDATIONS

1. Ensure that the sewage does not contaminate Hesse Lake or any water that returns to the Hesse Lake.
2. Decontaminate the entire plant by removing all accumulated deposits and chemically sterilizing the entire circuit.
3. Continue the chlorination of the process water until the assimilable sugar concentration reaches normal levels (15 micrograms per litre). The analytical procedure, for the determination of the sugar concentrations in water samples, is detailed in the Appendix.

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REFERENCES

1. Staff, Quebec-Cartier Mining Company - Mount Wright; In: Milling Practice in Canada; Edited by D.E. Pickett; Montreal,Canadian Institute of Mining and Metallurgy (CIM Special Volume 16); 266-268; 1978.

2. Smith, A.L., and Muia, R.A. "Identify and Control Microbiological Organisms in Cooling Water Systems"; Power 17-19 and 91-95; July, 1973.

3. Costerton, J.W.G., Irwin, R.T. and Cheng, K.J. "The Bacterial Glycocalyx in Nature and Disease"; Ann Rev Microbiol 35:299-324; 1981.

4. Stanier, R.Y., Doudoroff, M. and Adelberg, E.A. "The Microbial World" 3rd Edition; Englewood Cliffs, Prentice-Hall; 1970.

5. Collins, C.H. and Lyne, P.M. "Microbial Methods" 3rd Edition; London, Butterworths; 1970.

6. Umbreit, W.W., Burris, R.H. and Stauffer, J.F. "Manometric and Biochemical Techniques" 5th Edition; Minneapolis, Burgess; 1972.

7. Costerton, J.W. and Geesey, G.G. "Microbial Contamination of Surfaces"; In Surface Contamination; Edited by K.L. Mittal; New York, Plenum; 211 - 221; 1979.

8. Kuznetov, S.I., Dubimina, G.A. and Lapetea, N.A. "Biology of Oligotrophic Bacteria"; Ann Rev Micrbiol 33:377-387; 1979.

TABLE 1

Sample Description

Sample #	Location (See Fig. 2 & 3)	Remarks
1	Hesse Lake	Surface sample
2	Hesse Lake	Two feet below the surface
3	Discharge from plant	Approx. 25 feet upstream from intake
4	Ground water	Supposedly from underground.
5	Sump	In-take location for the pumps
6	Settling pond # 1	Surface sample
7	Settling pond # 2	Sewage from primary filtration and settling pond # 2 find their way to this pond.
8	Filtration lagoon	Very strong odour
9	Filtration tank	Water from Mogridge prior to filtration and chlorination
10	Filtration tank	Same as 9 except that it contained algal scrapings
11	Tap	Potable Mogridge water after filtration and chlorination.
12	Process sump	Approx. 1 part from Hesse Lake 2 parts from thickeners and the overflow from Mogridge.
13	Thickener # 1	Surface sample
14	Head tank for rougher spirals	Location indicatedonschematic block diagram
15	Head tank for cleaner spirals	Location indicated on schematic block diagram
16	Head tank for re-cleaner spirals	Location indicated on schematic block diagram
17	Recycle feed	The water fractions from coarse cleaner and recleaner spirals collection.
18	Mill discharge	Slurry from the grinding mill

TABLE 2

Composition of Defined Liquid Medium(4)

Component	Concentration (g/L)
Carbon Substrate	Variable
K_2HPO_4	1.0
$MgSO_4.7H_2O$	0.2
$FeSO_4.7H_2O$	0.01
$CaCl_2$	0.01
NH_4Cl	1.0
$MnSO_4$	0.001
pH 6.5	

The medium minus sugar substrate is sterilized at 121°C for 15 minutes. Sterile glucose or sucrose solutions are added to yield a final concentration of 0.1%. Calgon M 502, when used as substrate, is added to the solution at concentrations of 0.001 to 10% before sterilization.

TABLE 3

Identification of Microorganisms from the Organic Deposit on the Spiral Concentrator Surfaces and in the Process Water of the Quebec Cartier Mining Company Mount Wright Mill

Group	Bacteria Isolated from Organic Deposit	Bacteria Isolated from Process Water
Faecal Coliform Bacteria	Escherichia coli	Escherichia coli
	Klebsiella oxytoca	Klebsiella oxytoca
		Klebsiella ozaenae
Other Enteric Bacteria	Citrobacter freundii	Citrobacter amalonaticus
	Shigella sp.	Enterobacter agglomerans
		Providencia stuartii
		Shigella sp.
		Yersina pseudotuberculosus
Oxidative-Fementative Bacteria	Flavobacterium sp.	Flavobacterium sp.
	Pseudomonas fluorescens	Pseudomonas aeruginoa
	Pseudomonas putida	Pseudomonas sp.
Gram-positive Pleomorphic Bacteria	Corynebacteirum sp.	Arthrobacter sp
	Norcardia sp.	Corynebacteirum sp.
		Norcardia sp.
Other Micro-organisms	Torulopsis sp.	

TABLE 4

Concentrations of Bacteria in the Water Samples
(organisms/mL)

Sample #	Coliform Bacteria	Enteric Bacteria	Total Bacteria
1	92	500	2,450
2	82	318	1,580
3	181	2,565	20,000
4	0	8	649
5	13	96	324
6	2,017	12,200	273,800
7	290	1,930	67,933
8	1,017	5,380	163,800
9	199	426	970
10	5	23	930
11	0	0	432
12	19	75	1,245
13	108	255	830
14	39	154	1,175
15	25	65	1,570
16	22	103	1,260
17	75	274	4,400
18	320	15,500	38,000

TABLE 5

Concentrations of Carbohydrate Carbon, Total Organic Carbon and Total Dissolved Solids in Milligrams per Litre

Sample #	Carbohydrate Carbon	Total Organic Carbon	Total Dissolved Solids
1	3.0	5.5	100
2	2.4	7.0	100
3	1.6	9.5	181
4	1.1	11.0	65
5	2.2	5.9	101
6	4.1	8.5	71
7	3.5	13.0	80
8	4.8	8.6	60
9	1.6	7.9	36
10	0.6	9.8	33
11	0.7	6.1	30
12	4.0	18.0	135
13	4.7	5.8	120
14	4.7	5.7	124
15	4.4	5.6	115
16	4.3	7.2	114
17	0.8	11.0	115
18	1.0	25.0	215

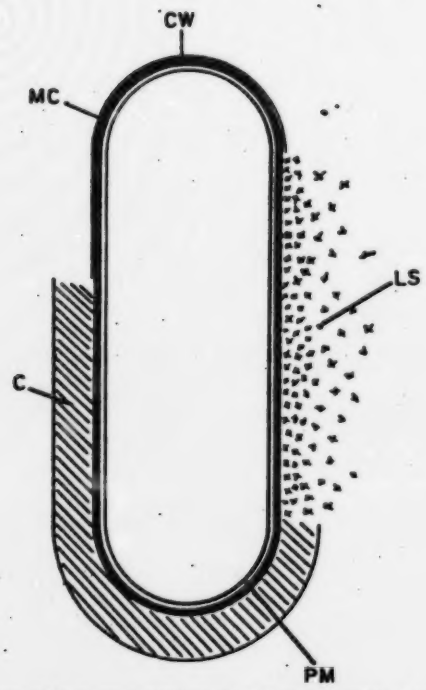

FIG. 1. A diagrammatic representation of the relationship between the capsules, slime, and microcapsular layers to the cell wall and protoplast membrane. CW = cell wall; PM = protoplasmic membrane; C = capsule; MC = microcapsule; LS = loose slime.

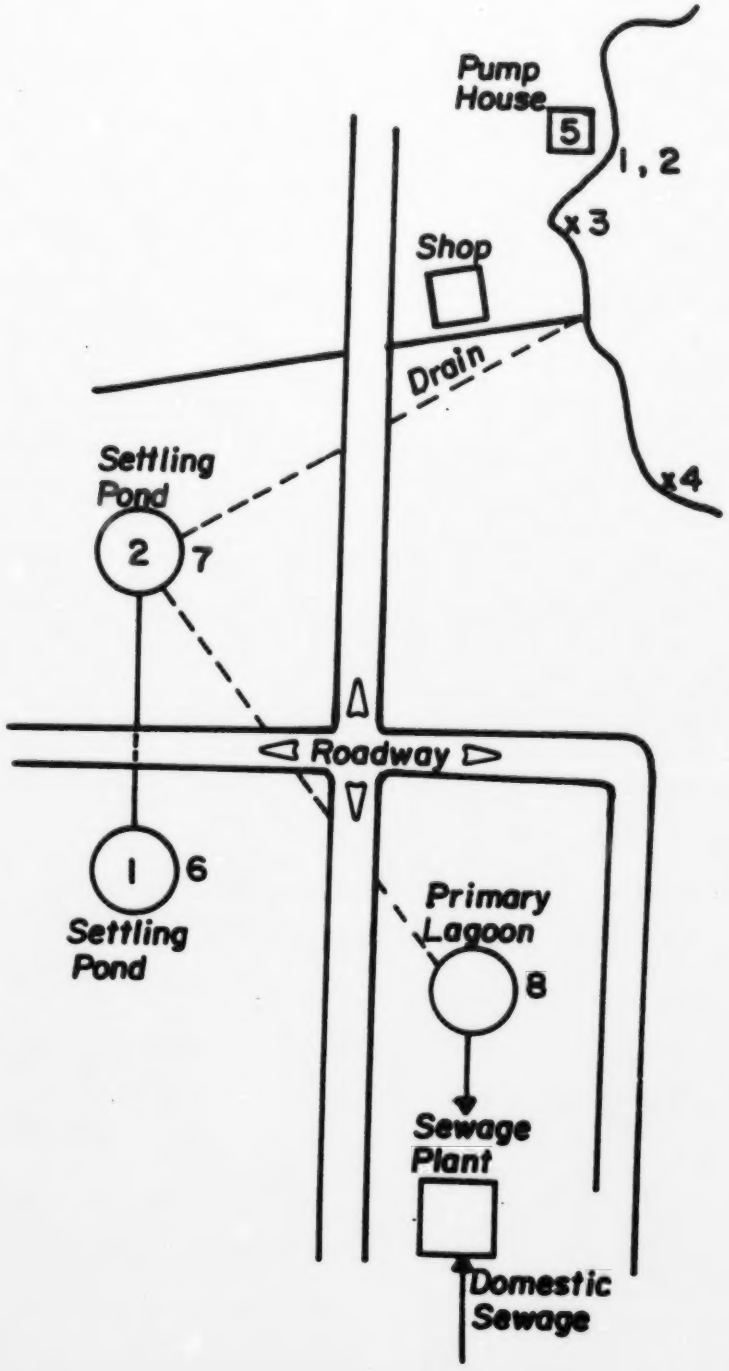

Figure 2. Sampling Locations 1 to 8

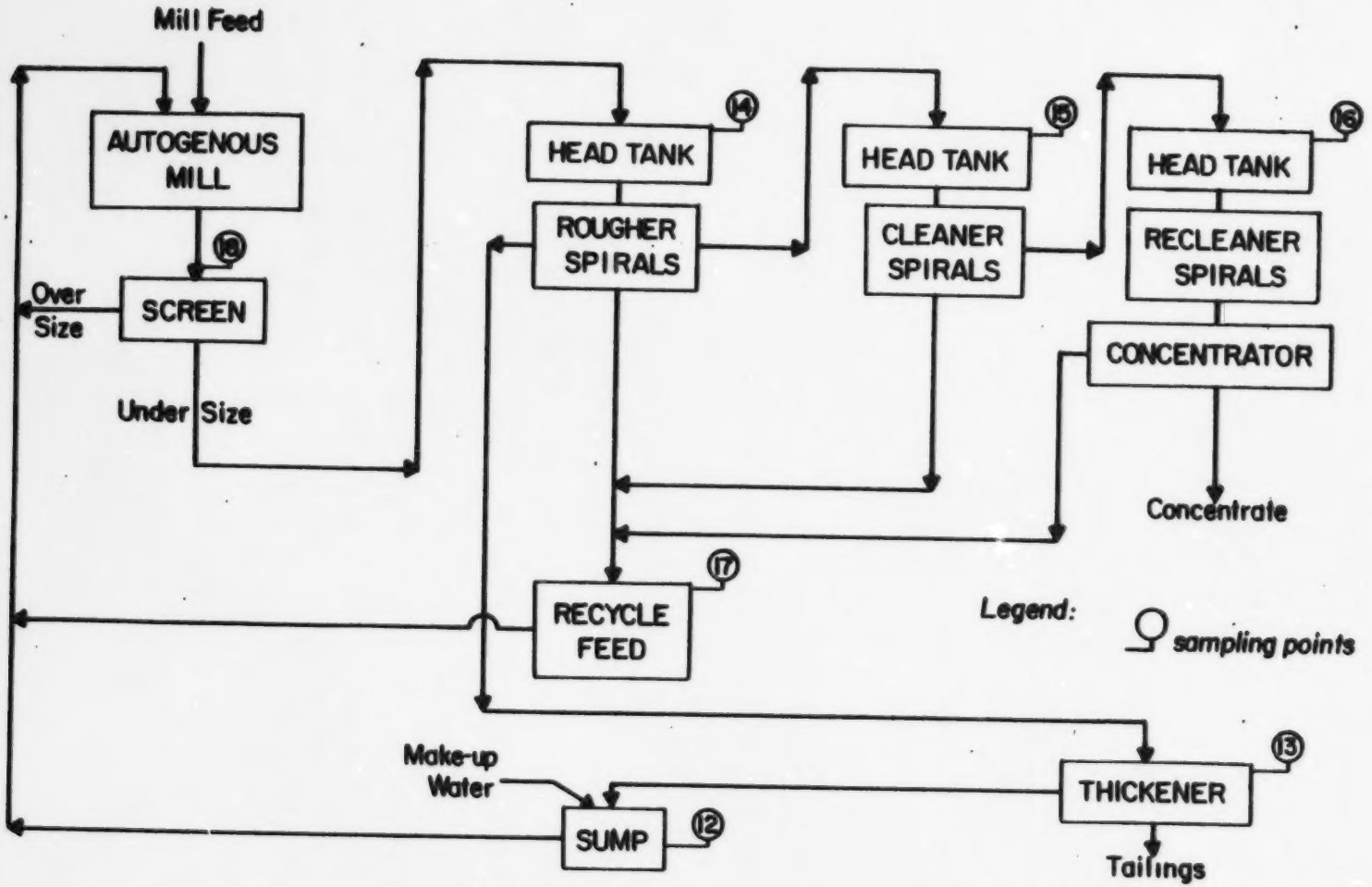

Figure 3 Schematic Block Diagram Showing Sampling Locations 12 to 18.

APPENDIX

METHOD FOR THE DETERMINATION OF TOTAL CARBOHYDRATE CONCENTRATION

Appendix - Method for the determination of total carbohydrate concentration

Reference: Umbreit, W.W., Burris, R.H. and Stauffer, J.F. "Manometric and Biochemical Techniques, 5th Edition. Minneapolis, Burgess (1972).

Anthrone (9-oxyanthracene) reacts with all carbohydrates (mono-, di-, oligo-, and polysaccharides) to give a characteristic blue colour, but the colour yield is not the same for all carbohydrates. As the standard used is glucose, the results can be described in terms of concentration of total carbohydrates as glucose, or can be multiplied by 0.4 and described as concentration of carbohydrate carbon.

Reagents: 1. The anthrone reagent consists of 2 g of anthrone (9-oxyanthracene) dissolved in 1 L of 95% reagent grade sulphuric acid (950 mL H_2SO_4 plus 50 mL distilled water). The reagent is unstable and must be prepared daily.

2. The glucose standard is prepared by adding 120 mg of reagent-grade glucose to 1 L of distilled water.

3. Distilled water.

Equipment and Supplies: 1. A spectrophotometer or colorimeter capable of use in determining optical density at 620 nm ($O.D._{620}$).

2. Acid washed test tubes of at least 15 mL capacity.

3. A matched set of spectrophotometer curvettes.

Procedure: To 3 mL of sample containing or diluted to contain 12 to 120 µg of carbohydrate (as glucose), add 6 mL of anthrone reagent and mix immediately. Heat for 3 min in a boiling water bath and cool to room temperature. Measure the optical density at 620 nm and compare to standards containing 12 to 120 µg of glucose.

Because the anthrone reagent is unstable and darkens with time, a fresh solution must be prepared daily and a set of standards must be included with each determination. Because of the corrosive nature of the reagent, which is prepared in 95% sulphuric acid, care must be exercised in handling of this reagent; spills must be avoided.

The colour developed by this method follows Beer's law, and the concentration can be calculated from the standard curve.

Calculation: mg/L carbohydrate as glucose = $\frac{AB}{C} \times \frac{1000}{D}$.

where A is the total number of milligrams in the standard, B is the optical density of the sample, C is the optical density of the standards, and D is the number of millilitres (3) of the sample. To convert the number of mg of glucose per litre to the number of mg of carbohydrate carbon per litre, multiply by 0.4.